

Examining Daily Associations among Sleep, Stress, and Blood Pressure across Adulthood

Supplemental Materials

We present the equations of each model run in the main text:

Model 1:

Check-in level: y_{ij} (physio/stress) = $\beta_{0j} + r_{ij}$

Person level: $\beta_{0j} = \gamma_{00} + \gamma_{01}$ (sleep variable) $_j + \gamma_{02-12}$ (covariates) $_j + u_{0j}$

Model 2:

Check-in level: y_{ij} (physio/stress) = $\beta_{0j} + \beta_{1j}$ (sleep variable) $_{ij} + r_{ij}$

Person level: $\beta_{0j} = \gamma_{00} + u_{0j}$

$$\beta_{1j} = \gamma_{10} + u_{1j}$$

Model 3:

Check-in level: y_{ij} (physio/stress) = $\beta_{0j} + r_{ij}$

Person level: $\beta_{0j} = \gamma_{00} + \gamma_{01}$ (sleep variable) $_j + \gamma_{02}$ (age) $_j + \gamma_{03}$ (sleep variable*age) $_j + \gamma_{04-14}$ (covariates) $_j + u_{0j}$

Model 4:

Check-in level: y_{ij} (physio/stress) = $\beta_{0j} + \beta_{1j}$ (sleep) $_{ij} + r_{ij}$

Person level: $\beta_{0j} = \gamma_{00} + \gamma_{01}$ (age) $_j + \gamma_{02-012}$ (covariates) $_j + u_{0j}$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}$$
 (age) $_j + \gamma_{12-112}$ (covariates) $_j + u_{1j}$

In addition to the descriptive statistics reported in the main text, we used the program Mplus Version 8.4 to examine the within-person correlations between each of the sleep measures based on a maximum-likelihood estimation of the within-person covariance matrix. We also aggregated each sleep measure across check-ins and examined the between-person correlations between each sleep measure. The correlations between the sleep variables were moderate in magnitude, suggesting that the sleep measures are related but provide unique information (see Supplemental Table 1).

Supplemental Table 1. Within- and between-person correlation matrix of all daily sleep measures.

	Sleep duration	Sleep efficiency	Subjective sleep quality
Sleep duration (hrs)		.59	.31
Sleep efficiency (%)	.60		.48
Subjective sleep quality	.34	.37	

Note: Within-person correlations are presented below the diagonal. Between-person correlations are presented above the diagonal.

In the main text, we present one effect size estimate for the within-person analyses. Here we present the same results with additional columns for the additional effect size estimates based on the variance reductions from the fixed effects and random effects portions of the models.

Supplemental Table 2. Within-person relationships between sleep and physiologic/stress outcomes.

<u>Predictors</u>								
Sleep Duration								
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	$r_w^{(f)}$	$r_w^{(fI)}$	$r_w^{(fv)}$
Heart rate	3,089	20,966	-.30	-5.88	< .001	.14	.05	.13
Systolic blood pressure	2,401	16,293	-.10	-2.18	.029	.12	.02	.12
Diastolic blood pressure	2,401	16,293	-.00	-.08	.937	.13	.00	.13
Stress	2,861	19,169	-.05	-10.54	< .001	.16	.09	.14
Sleep Efficiency								
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	$r_w^{(f)}$	$r_w^{(fI)}$	$r_w^{(fv)}$
Heart rate	3,087	20,945	-.03	-3.87	< .001	.10	.03	.10
Systolic blood pressure	2,399	16,282	-.01	-1.14	.254	.01	.01	.00
Diastolic blood pressure	2,399	16,282	.00	.30	.768	.00	.00	.00
Stress	2,857	19,151	-.00	-8.07	< .001	.15	.08	.13
Sleep Quality								
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	$r_w^{(f)}$	$r_w^{(fI)}$	$r_w^{(fv)}$
Heart rate	4,235	26,218	-.65	-6.13	< .001	.14	.04	.14
Systolic blood pressure	3,107	19,594	-.39	-4.07	< .001	.09	.03	.09
Diastolic blood pressure	3,107	19,594	-.14	-1.97	.049	.10	.02	.10
Stress	3,844	23,551	-.16	-16.68	< .001	.19	.12	.14

Note: Effect sizes, $r_w^{(f)}$, were calculated following recommendations by Rights and Sterba (2019). The $r_w^{(f)}$ statistic is defined as the square root of the proportion of variance explained by within-person predictors via fixed slopes and random slope variation/covariation. This is similar to a measure of the square root of the proportion reduction in variance, akin to a correlation (32–34), but it may not correspond intuitively to t -values and p -values. The $r_w^{(f)}$ statistic refers to the variance associated specifically with the fixed effects, whereas the $r_w^{(fv)}$ statistic refers to the variance associated with the random slope variation/covariation. The $r_w^{(f)}$ statistic more closely aligns with the t -values and p -values, but we reported the $r_w^{(fv)}$ statistic in the manuscript because that statistic most closely corresponds to the effect size estimates that have been used in prior research.

Supplemental Table 3. Interaction coefficients of age moderation of between-person relationships.

Predictors					
Sleep Duration					
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>
Heart rate	2,780	18,919	-.00	-.16	.875
Systolic blood pressure	2,160	14,616	.02	.97	.332
Diastolic blood pressure	2,160	14,616	-.02	-.94	.347
Stress	2,578	17,324	.00	1.25	.211
Sleep Efficiency					
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>
Heart rate	2,778	18,899	-.00	-.16	.876
Systolic blood pressure	2,158	14,606	.00	.88	.379
Diastolic blood pressure	2,158	14,606	-.00	-1.31	.190
Stress	2,574	17,307	.00	.84	.402
Sleep Quality					
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>
Heart rate	3,795	23,535	.02	.54	.585
Systolic blood pressure	2,783	17,492	.01	.26	.798
Diastolic blood pressure	2,783	17,492	-.06	-1.80	.072
Stress	3,460	21,228	.00	1.47	.141

Supplemental Table 4. Between-person relationships between aggregated sleep measures and physiologic/stress outcomes among participants who completed at least 3-check-ins, at least 5-check-ins, and at least 7-check-ins.

DV	Cutoff	<u>Predictors</u>					
		Sleep Duration					
		<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_b^(f)</i>
Heart rate	3	2,780	18,919	-1.09	-6.33	< .001	.13
Heart rate	5	1,606	14,957	-1.12	-4.47	< .001	.13
Heart rate	7	1,060	11,989	-1.02	-3.19	.001	.11
Systolic blood pressure	3	2,160	14,616	-.13	-.46	.648	.02
Systolic blood pressure	5	1,259	11,558	-.88	-2.18	.030	.04
Systolic blood pressure	7	837	9,282	-1.52	-3.13	.002	.09
Diastolic blood pressure	3	2,160	14,616	-.13	-.65	.514	.03
Diastolic blood pressure	5	1,259	11,558	-.52	-1.81	.070	.05
Diastolic blood pressure	7	837	9,282	-.71	-2.02	.044	.08
Stress	3	2,578	17,324	-.07	-6.04	< .001	.11
Stress	5	1,484	13,623	-.08	-4.85	< .001	.14
Stress	7	963	10,806	-.09	-4.30	< .001	.17
DV	Cutoff	Sleep Efficiency					
		<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_b^(f)</i>
		Heart rate	3	2,778	18,899	-.13	-5.02
Heart rate	5	1,605	14,943	-.15	-4.10	< .001	.13

Heart rate	7	1,059	11,977	-.17	-3.65	< .001	.14
Systolic blood pressure	3	2,158	14,606	-.05	-1.09	.276	.04
Systolic blood pressure	5	1,259	11,555	-.14	-2.36	.018	.06
Systolic blood pressure	7	837	9,279	-.11	-1.50	.133	.05
Diastolic blood pressure	3	2,158	14,606	-.02	-.65	.515	.02
Diastolic blood pressure	5	1,259	11,555	-.08	-1.76	.078	.03
Diastolic blood pressure	7	837	9,279	-.04	-.73	.467	.03
Stress	3	2,574	17,307	-.01	-8.15	< .001	.18
Stress	5	1,482	13,612	-.02	-7.09	< .001	.22
Stress	7	962	10,799	-.02	-5.78	< .001	.23

Sleep Quality

DV	Cutoff	N	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_b^(f)</i>
Heart rate	3	3,795	23,535	-1.78	-4.76	< .001	.13
Heart rate	5	1,975	17,373	-1.64	-2.91	.004	.11
Heart rate	7	1,175	13,039	-1.35	-1.84	.066	.10
Systolic blood pressure	3	2,783	17,492	-2.14	-3.57	< .001	.05
Systolic blood pressure	5	1,492	13,107	-2.02	-2.33	.020	.05
Systolic blood pressure	7	911	9,979	-2.31	-2.18	.030	.05
Diastolic blood pressure	3	2,783	17,492	-1.47	-3.35	< .001	.09
Diastolic blood pressure	5	1,492	13,107	-1.50	-2.38	.017	.09
Diastolic blood pressure	7	911	9,979	-1.10	-1.41	.160	.09
Stress	3	3,460	21,228	-.36	-14.47	< .001	.28

Stress	5	1,783	15,563	-.41	-12.14	< .001	.33
Stress	7	1,051	11,606	-.45	-10.37	< .001	.35

Supplemental Table 5. Within-person relationships between sleep and physiologic/stress outcomes among participants who completed at least 3-check-ins, at least 5-check-ins, and at least 7-check-ins.

		<u>Predictors</u>					
		Sleep Duration					
DV	Cutoff	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_w^(f)</i>
Heart rate	3	3,089	20,966	-.30	-5.88	< .001	.14
Heart rate	5	1,781	16,558	-.30	-5.16	< .001	.14
Heart rate	7	1,176	13,270	-.34	-5.15	< .001	.15
Systolic blood pressure	3	2,401	16,293	-.10	-2.18	.029	.12
Systolic blood pressure	5	1,406	12,918	-.13	-2.58	.010	.14
Systolic blood pressure	7	937	10,385	-.13	-2.22	.027	.16
Diastolic blood pressure	3	2,401	16,293	-.00	-.08	.937	.13
Diastolic blood pressure	5	1,406	12,918	-.03	-.61	.542	.15
Diastolic blood pressure	7	937	10,385	-.02	-.42	.675	.16
Stress	3	2,861	19,169	-.05	-10.54	< .001	.16
Stress	5	1,641	15,053	-.05	-9.32	< .001	.15
Stress	7	1,066	11,946	-.05	-8.32	< .001	.16
		Sleep Efficiency					
DV	Cutoff	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_w^(f)</i>
Heart rate	3	3,087	20,945	-.03	-3.87	< .001	.10
Heart rate	5	1,779	16,539	-.03	-3.61	< .001	.10

Heart rate	7	1,175	13,258	-.03	-3.62	< .001	.11
Systolic blood pressure	3	2,399	16,282	-.01	-1.14	.254	.01
Systolic blood pressure	5	1,405	12,910	-.01	-1.54	.123	.02
Systolic blood pressure	7	937	10,382	-.01	-1.24	.214	.01
Diastolic blood pressure	3	2,399	16,282	.00	.30	.768	.00
Diastolic blood pressure	5	1,405	12,910	-.00	-.05	.961	.00
Diastolic blood pressure	7	937	10,382	.00	.26	.798	.00
Stress	3	2,857	19,151	-.00	-8.07	< .001	.15
Stress	5	1,638	15,037	-.00	-7.07	< .001	.14
Stress	7	1,065	11,939	-.00	-6.38	< .001	.16

Sleep Quality

DV	Cutoff	N	# Check-ins	b	t	p	$r_w^{(f)}$
Heart rate	3	4,235	26,218	-.65	-6.13	< .001	.14
Heart rate	5	2,195	19,315	-.61	-5.19	< .001	.13
Heart rate	7	1,309	14,516	-.56	-4.16	< .001	.13
Systolic blood pressure	3	3,107	19,594	-.39	-4.07	< .001	.09
Systolic blood pressure	5	1,671	14,715	-.41	-3.79	< .001	.09
Systolic blood pressure	7	1,023	11,225	-.30	-2.43	.015	.10
Diastolic blood pressure	3	3,107	19,594	-.14	-1.97	.049	.10
Diastolic blood pressure	5	1,671	14,715	-.16	-1.98	.047	.11
Diastolic blood pressure	7	1,023	11,225	-.13	-1.49	.137	.11
Stress	3	3,844	23,551	-.16	-16.68	< .001	.19
Stress	5	1,975	17,251	-.15	-14.08	< .001	.18

Stress	7	1,167	12,884	-.14	-11.83	< .001	.18
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Supplemental Table 6. Interaction coefficients of age moderation of between-person relationships among participants who completed at least 3-check-ins, at least 5-check-ins, and at least 7-check-ins.

Predictors						
Sleep Duration						
DV	Cutoff	N	# Check-ins	b	t	p
Heart rate	3	2780	18919	-.00	-.16	.875
Heart rate	5	1606	14957	.01	.28	.782
Heart rate	7	1060	11989	-.01	-.23	.821
Systolic blood pressure	3	2160	14616	.02	.97	.332
Systolic blood pressure	5	1259	11558	.04	1.25	.213
Systolic blood pressure	7	837	9282	.04	.99	.321
Diastolic blood pressure	3	2160	14616	-.02	-.94	.347
Diastolic blood pressure	5	1259	11558	-.02	-.81	.417
Diastolic blood pressure	7	837	9282	-.02	-.92	.357
Stress	3	2578	17324	.00	1.25	.211
Stress	5	1484	13623	-.00	-.55	.581
Stress	7	963	10806	-.00	-.13	.896
Sleep Efficiency						
DV	Cutoff	N	# Check-ins	b	t	p
Heart rate	3	2778	18899	-.00	-.16	.876
Heart rate	5	1605	14943	-.00	-.95	.343

Heart rate	7	1059	11977	-.01	-2.05	.040
Systolic blood pressure	3	2158	14606	.00	.88	.379
Systolic blood pressure	5	1259	11555	.00	.27	.789
Systolic blood pressure	7	837	9279	.00	.51	.610
Diastolic blood pressure	3	2158	14606	-.00	-1.31	.190
Diastolic blood pressure	5	1259	11555	-.00	-.90	.369
Diastolic blood pressure	7	837	9279	.00	.11	.913
Stress	3	2574	17307	.00	.84	.402
Stress	5	1482	13612	-.00	-.61	.543
Stress	7	962	10799	-.00	-.51	.613

Sleep Quality

DV	Cutoff	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>
Heart rate	3	3795	23535	.02	.54	.585
Heart rate	5	1975	17373	.02	.54	.588
Heart rate	7	1175	13039	-.07	-1.22	.224
Systolic blood pressure	3	2783	17492	.01	.26	.798
Systolic blood pressure	5	1492	13107	-.02	-.29	.772
Systolic blood pressure	7	911	9979	-.03	-.31	.759
Diastolic blood pressure	3	2783	17492	-.06	-1.80	.072
Diastolic blood pressure	5	1492	13107	-.03	-.64	.524
Diastolic blood pressure	7	911	9979	-.04	-.63	.529
Stress	3	3460	21228	.00	1.47	.141

Stress	5	1783	15563	.00	1.85	.065
Stress	7	1051	11606	.01	1.72	.087

Supplemental Table 7. Cross-level interaction coefficients of age moderation of within-person relationships among participants who completed at least 3-check-ins, at least 5-check-ins, and at least 7-check-ins.

		Predictors				
		Sleep Duration				
DV	Cutoff	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>
Heart rate	3	2780	18919	.010	2.27	.023
Heart rate	5	1606	14957	.013	2.69	.007
Heart rate	7	1060	11989	.015	2.76	.006
Systolic blood pressure	3	2160	14616	.012	2.60	.009
Systolic blood pressure	5	1259	11558	.014	2.82	.005
Systolic blood pressure	7	837	9282	.009	1.47	.142
Diastolic blood pressure	3	2160	14616	.007	2.09	.036
Diastolic blood pressure	5	1259	11558	.008	2.10	.036
Diastolic blood pressure	7	837	9282	.002	.37	.713
Stress	3	2578	17324	.000	.61	.540
Stress	5	1484	13623	.000	1.01	.314
Stress	7	963	10806	.000	.89	.373
		Sleep Efficiency				
DV	Cutoff	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>
Heart rate	3	2778	18899	.001	.96	.339
Heart rate	5	1605	14943	.000	.93	.354

Heart rate	7	1059	11977	.001	.63	.532
Systolic blood pressure	3	2158	14606	.001	1.32	.188
Systolic blood pressure	5	1259	11555	.001	1.56	.120
Systolic blood pressure	7	837	9279	.000	.25	.805
Diastolic blood pressure	3	2158	14606	.001	1.49	.136
Diastolic blood pressure	5	1259	11555	.001	1.48	.139
Diastolic blood pressure	7	837	9279	.000	.36	.723
Stress	3	2574	17307	.000	.01	.989
Stress	5	1482	13612	.000	.06	.955
Stress	7	962	10799	-.000	-.61	.540

Sleep Quality

DV	Cutoff	N	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>
Heart rate	3	3795	23535	.023	2.42	.016
Heart rate	5	1975	17373	.023	2.13	.033
Heart rate	7	1175	13039	.017	1.39	.166
Systolic blood pressure	3	2783	17492	.022	2.45	.014
Systolic blood pressure	5	1492	13107	.022	2.12	.034
Systolic blood pressure	7	911	9979	.018	1.52	.129
Diastolic blood pressure	3	2783	17492	.007	.95	.345
Diastolic blood pressure	5	1492	13107	.003	.33	.744
Diastolic blood pressure	7	911	9979	-.001	-.12	.901
Stress	3	3460	21228	.002	2.46	.014

Stress	5	1783	15563	.002	2.45	.015
Stress	7	1051	11606	.002	1.91	.056

Supplemental Table 8. Between-person relationships between aggregated sleep measures (including sleep midpoint) and physiologic/stress outcomes.

<u>Predictors</u>						
Sleep Duration						
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_b^(f)</i>
Heart rate	2,780	18,919	-1.09	-6.33	< .001	.13
Systolic blood pressure	2,160	14,616	-.13	-.46	.648	.02
Diastolic blood pressure	2,160	14,616	-.13	-.65	.514	.03
Stress	2,578	17,324	-.07	-6.04	< .001	.11
Sleep Efficiency						
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_b^(f)</i>
Heart rate	2,778	18,899	-.13	-5.02	< .001	.13
Systolic blood pressure	2,158	14,606	-.05	-1.09	.276	.04
Diastolic blood pressure	2,158	14,606	-.02	-.65	.515	.02
Stress	2,574	17,307	-.01	-8.15	< .001	.18
Sleep Midpoint						
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_b^(f)</i>
Heart rate	3,719	23,001	-.20	-1.23	.218	.00
Systolic blood pressure	2,735	17,137	-.37	-1.48	.140	.05
Diastolic blood pressure	2,735	17,137	-.23	-1.23	.221	.03
Stress	3,394	20,795	-.01	-1.25	.211	.00

Sleep Quality

DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_b^(f)</i>
Heart rate	3,795	23,535	-1.78	-4.76	< .001	.13
Systolic blood pressure	2,783	17,492	-2.14	-3.57	< .001	.05
Diastolic blood pressure	2,783	17,492	-1.47	-3.35	< .001	.09
Stress	3,460	21,228	-.36	-14.47	< .001	.28

Supplemental Table 9. Within-person relationships between sleep (including sleep midpoint) and physiologic/stress outcomes.

<u>Predictors</u>						
Sleep Duration						
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_w^(f)</i>
Heart rate	3,089	20,966	-.30	-5.88	< .001	.14
Systolic blood pressure	2,401	16,293	-.10	-2.18	.029	.12
Diastolic blood pressure	2,401	16,293	-.00	-.08	.937	.13
Stress	2,861	19,169	-.05	-10.54	< .001	.16
Sleep Efficiency						
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_w^(f)</i>
Heart rate	3,087	20,945	-.03	-3.87	< .001	.10
Systolic blood pressure	2,399	16,282	-.01	-1.14	.254	.01
Diastolic blood pressure	2,399	16,282	.00	.30	.768	.00
Stress	2,857	19,151	-.00	-8.07	< .001	.15
Sleep Midpoint						
DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_w^(f)</i>
Heart rate	4,138	25,556	-.29	-4.23	< .001	.15
Systolic blood pressure	3,045	19,146	.03	.52	.606	.07
Diastolic blood pressure	3,045	19,146	.02	.37	.712	.11
Stress	3,765	23,033	-.05	-8.12	< .001	.12

Sleep Quality

DV	<i>N</i>	# Check-ins	<i>b</i>	<i>t</i>	<i>p</i>	<i>r_w^(f)</i>
Heart rate	4,235	26,218	-.65	-6.13	< .001	.14
Systolic blood pressure	3,107	19,594	-.39	-4.07	< .001	.09
Diastolic blood pressure	3,107	19,594	-.14	-1.97	.049	.10
Stress	3,844	23,551	-.16	-16.68	< .001	.19

Finally, we report supplemental analyses concerning quadratic effects of sleep duration at between and within-person levels of analysis. Between-persons, we found an inverse J-shaped quadratic effect for heart rate, $b = .22$, $t = 2.92$, $p = .004$, such that people who sleep less than five hours/night on average report the highest levels of heart rate on average; people who sleep between 8-9 hours/night report the lowest average heart rate; and those who sleep more than 9 hours/night report elevated heart rate levels (although not as high as those who sleep less than 5 hours/night). The non-linear effects for SBP, DBP, and stress were not significant ($ps = .564$, $.162$, and $.130$, respectively). Within-persons, the non-linear associations were not significant for heart rate, SBP, or DBP ($ps = .668$, $.498$, and $.336$, respectively), but we found a cubic relationship for stress, $b = -.004$, $t = -2.81$, $p = .005$. However, the cubic relationship did not fit the typical U-shaped or J-shaped pattern but looked more similar to a negative linear relationship.